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RESEARCH PAPER

Replacing Steel Cable with Synthetic Rope to Reduce Operator Workload During Log Winching Operations

Natascia Magagnotti · Raffaele Spinelli

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Abstract The authors conducted three comparative tests, to determine if the replacement of steel cable with synthetic rope may allow reducing the physiological workload of forest operators assigned to log winching tasks. The tests were conducted in Northern Italy, on the Alpine mountain and involved 7 volunteer subjects. The physiological workload was determined by measuring the operator's heart rate upon completion of every task, using heart-rate monitors. Test one was conducted under simplified, controlled conditions and detected a statistically significant reduction of relative heart rate when carrying synthetic rope, as compared to steel cable. However, tests two and three were performed under real operational conditions, and were inconclusive. Real operational conditions are characterized by the interaction of many factors, which may confound the results of the tests, or offset the benefits potentially obtained with the introduction of synthetic rope. Nevertheless, the introduction of synthetic rope offers the benefit of easier handling, which was very much appreciated by all test subjects.

Keywords Ergonomics · Fatigue · Technology · Harvesting

Introduction

Despite the rapid progress of forest mechanization, small-scale forestry owners often resort to intermediate harvesting technology (Lindroos et al. 2005), which offers a more acceptable balance between capital and labour inputs (Dubey 2008).

N. Magagnotti
DEIAGRA, University of Bologna, Via Fanin 50, 40127 Bologna, BO, Italy
e-mail: magagnotti@ivalsa.cnr.it

R. Spinelli (✉)
CNR, Timber and Tree Institute, Via Madonna del Piano 10, 50019 Sesto Fiorentino, FI, Italy
e-mail: spinelli@ivalsa.cnr.it

Winches are still very popular among small-scale forest operators (De Warnaffe et al. 2006), who often adapt the original winching concept with much ingenuity (Spinelli and Magagnotti 2011). However, motor-manual logging operations impose a heavy strain on the respiratory and circulatory systems (Kukkonen-Harjula and Rauramaa 1984; Harstela 1990) and are considered as strenuous physical work (Åstrand and Rodahl 1988). This results in the prevalence of musculoskeletal disorders (MSD) among motor-manual forest workers (Riihimäki 1986). The problem is common to all European countries, from Sweden (Pontén 1988) to Greece (Gallis 2006). That represents a very serious threat to European small-scale forestry, given the progressive aging of active forest owners (Hogl et al. 2005), and in general of the forestry workforce (Tsioras 2011).

Physical strain and the occurrence of MSD are related to the handling of heavy objects, such as work tools (Jørgensen et al. 1985). Significant benefits can be obtained from reducing the weight of existing tools (Putz-Anderson 1988). This strategy has already been tested with success in other sectors, such as construction work (Molen et al. 1998). In motor-manual forest operations, a unique opportunity to reduce the mass of work tools is offered by synthetic rope, recently introduced to logging operations as a lighter replacement of conventional steel cable (Golsse 1996). This may partly alleviate the burden of winching work, where the operators have to drag a substantial length of steel cable all the way to the logs, for hooking them to the mainline (Carbaugh and Hensle 2005). Winching is still very popular with small companies and part-time loggers, who often use forestry-fitted farm tractors for their log extraction needs (Horvat et al. 2005; Picchio et al. 2009).

The technical effectiveness of synthetic rope for logging applications has already been demonstrated by several studies, some specifically addressing its use on forestry winches (Pilkerton et al. 2003). In general, technical tests have shown that synthetic rope is suitable for logging applications, where it offers the same general performance as steel rope (Pilkerton et al. 2004a). After developing suitable end connectors (Hartter and Garland 2006), the main disadvantage of synthetic rope consists only in a much higher cost compared to steel cable (Garland et al. 2001). However, very few peer-reviewed studies address the actual ergonomic benefits of synthetic rope, and in particular the workload reduction eventually obtained when steel cable is replaced by synthetic rope in winching applications. Therefore, the goal of this study was to gauge the workload mitigation potential offered by synthetic rope, using experimental and statistical methods under both controlled and real operational conditions. This was obtained by comparing the physical workloads experienced by a sample of forest workers using synthetic rope and conventional steel cable for direct winching.

Materials and Methods

The study consisted of three comparative tests, administered to seven workers from two different crews. Subjects were chosen randomly from a larger pool of volunteers and were considered representative of the logger population in the Italian Alps (Table 1). All the subjects were mesomorphic adult males.

Table 1 Physical characteristics of the volunteer test subjects

Crew no.	Subject	Age (years)	Weight (kg)	Height (cm)	HR rest (bpm)	HR max (bpm)	Smoker Y/N	Test no.
1	A	33	74	175	67	187	N	1, 2
1	B	26	70	170	70	194	Y	1, 2
1	C	42	80	174	52	178	N	1
1	D	42	80	186	76	178	N	1
2	E	42	72	174	65	178	N	3
2	F	64	72	170	50	156	N	3
2	G	37	74	174	60	183	N	3

In the first test, four workers from crew 1 were asked to carry a coil of steel cable and a coil of synthetic rope over a distance of 35 m, working in pairs. Both coils contained 150 m of 12 mm cable and weighed 73 and 12 kg, for steel cable and synthetic rope, respectively. The weight reduction factor offered by the synthetic rope treatment was 6. The same operators were then asked to carry a motorized mini-winch over the same distance, after equipping the machine with 80 m of 10 mm cable. The total weight of the tool was 81 and 57 kg, when equipped with steel cable and synthetic rope, respectively. In this case, the weight reduction factor for the synthetic rope treatment was 1.4. The winch was mounted on a stretcher, so that the four workers could all work together. Each test was repeated 10 times, 5 for the steel cable and 5 for the synthetic rope treatment. Each repetition was performed only after the heart rates of all workers had slowed down to resting values. This work was conducted in flat terrain, and ground slope was not a factor. The test replicated the procedure used by Garland et al. (2002) and simulated cable and winch relocation, normally occuring several times per day.

In the second test, the same mini-winch was used for bunching beech trees during a motor-manual coppice harvesting operation (Table 2). Two of the operators volunteering for the first test acted as choker setters. Their task included four activities: (1) pulling the winch mainline uphill to the loads, (2) hooking the loads with standard choker chains, (3) following the load back to the winch, and (4) releasing the choker chains. The weight of the steel cable was 28 kg, and that of the synthetic rope was 5 kg. The 6 mm choker chain and the hook were made of hardened steel and weighed 2.7 kg. The weight reduction factor offered by the synthetic rope treatment was 5.6. Of the two operators, subject A would carry the cable, whereas subject B would only carry the choker chain. This was done with the double purpose of (1) providing a control for possible variations of workload and/or work pace, and (2) maintaining the weight reduction factor unaltered, by dissociating the carrying of the winch line from that of the choker chains. The test lasted 31 h (3.8 work days), and the winch mainline was replaced four times a day, alternating steel cable and synthetic rope, so as to perform 50 complete work cycles for each treatment. The loads were winched downhill, so that workers had to walk uphill when pulling the winch mainline.

Table 2 Description of the test sites

Test	No.	1	2	3
Municipality		Selva di Progno	Roverè V.se	Cavalese
Northing		45°36′26.18″	45°39′02.43″	45°16′37.69″
Easting		11°08′29.19″	11°06′26.56″	11°34′09.70″
Elevation	m asl	539	1,270	1,162
Slope gradient	%	0–2	15–45	25–30
Operation		Carrying	Winching	Winching
Pulling out of rope	Direction	–	Uphill	Downhill
Maximum distance	m	35	76	88
Conditions		Controlled	Real	Real
Duration	Hours	1	31	31
Repetitions	n.	20	105	126

Repetitions were evenly distributed between the two treatments

In the third test, three workers from crew no 2 winched spruce logs to the roadside, using a forestry winch installed on a farm tractor. The winch had two drums, so that steel cable could be mounted on one drum, and synthetic rope on the other. Both cable segments were 100 m long and had a diameter of 10 mm. The total weight of the steel cable was 35 kg, and that of the synthetic rope 6.3 kg. The weight reduction factor was 5.6. However, both treatments included the installation of two sliders on the winch line and the use of two 8 mm choker chains, each measuring 2 m. Choker chains, hooks and sliders were made of hardened steel and added 7.8 kg to both treatments. Hence, the actual weight reduction factor offered by the synthetic rope treatment was decreased to 3. This test also lasted 31 h (3.8 work days), during which three operators took turns at pulling the mainline to the loading point. Each turn included five consecutive pulls with the steel cable and five with the synthetic rope, after which the operator was replaced by a colleague. The loads were winched uphill, so that workers had to walk downhill when pulling the winch mainline.

Workload was estimated on the basis of heart rate only. This is considered an effective indicator of the physiological strain of subjects in applied field situations, where the direct measurement of other parameters such as V_{O_2} max (i.e. maximal oxygen consumption, or the maximum capacity of an individual's body to transport oxygen during incremental exercise) is relatively difficult to obtain (Kirk and Sullman 2001). Polar S 120 (www.polar.fi) sport heart rate monitors were used for all tests. The use of sport heart rate monitors for research has already been validated by several studies (Vogelaere et al. 1986, Leger and Thivierge 1988). Monitor readings were used to determine operator working heart rate at the end of each activity (Bergstrand 1991). Test one included only one activity, i.e. carrying the rope coils or the mini-winch over a 35 m distance. Hence, heart rate was recorded upon arrival to the 35 m line. In tests two and three, four main work activities were considered, and namely: (1) pulling the rope from the winch to the loading point, (2) hooking the load, (3) walking alongside the load and back to the winch, and (4)

unhooking the load. Further non-cyclic activities were also included, such as repairs, delays, rest and other pauses (Björheden et al. 1995). Working heart rate readings were collected at the end of each activity, alongside with the time taken to complete the activity itself. Each record also included measures of the main factors that could affect activity duration and operator workload, such as the distance actually walked and the slope gradient. Walking distance was determined with a laser range finder, and slope gradient with an inclinometer. All data were collected using Husky Hunter hand-held field computers running the dedicated Siwork3 time study software (Kofman 1995). Resting heart rate was obtained for each subject upon arrival to the work site and before starting the work day. Subjects were asked to remain seated inside their cars as comfortably as possible, without moving, drinking or smoking for a minimum time of 10 min, after which their heart rates were recorded. Maximum heart rate was estimated with the standard formula HRmax = 220—age (Rodahl 1989). Relative heart rate at work was calculated as follows: (Vitalis 1987):

$$\%\mathrm{HRR} = \frac{\mathrm{HRwork} - \mathrm{HRrest}}{\mathrm{HRmax} - \mathrm{HRrest}} \times 100$$

where: %HRR = Relative heart rate at work, in percent; HRwork = Heart rate at work (end of the work activity); HRrest = Heart rate at rest; HRmax = Maximum heart rate.

Relative heart rate at work is an indicator of how deeply an activity is tapping into the operator's physiological reserve. It represents the main reference value in many studies addressing the physiological strain experienced by forest workers (Apud 1989, Kirk and Parker 1994).

Data were analyzed with the Statview advanced statistics software. ANOVA techniques were used to check the statistical significance of the eventual differences between treatments and operators (SAS 1999).

All tests were conducted during summer, on the Alpine mountain. Air temperature varied from 17 to 26°C (mean 20.7°C). Air pressure varied from 822 to 839 mbar, with an average value of 833. However, the authors did not record and associate individual air temperature/pressure readings to their observations, on the assumption that these factors would equally affect both treatments and would not constitute a significant covariate in the study.

Results

Table 3 shows the results of test 1, in terms of both relative heart rate at work and progression speed. These parameters must always be evaluated in conjunction, in order to fully appreciate the effect of workload. Physiological workload may reflect on relative heart rate as well as on performance, because operators may reduce their work rate in the face of a more challenging work condition so as to maintain a steady level of physiological workload (Vogt et al. 1983, Smith and Rummer 1988). Overall, the replacement of steel cable with synthetic rope resulted in a statistically significant reduction of relative heart rate. Conversely, work pace increases significantly when shifting to synthetic rope. Such differences are more significant

Table 3 Test 1: comparison of relative heart rate and work pace (20 cycles)

Results for		Steel	Synthetic	*P*
Cable coil	%HRR	28.9	24.6	0.046
(carried by pairs)	km h^{-1}	4.4	5.1	<0.001
Mini-winch	%HRR	27.4	26.0	0.646
(carried by 4 men)	km h^{-1}	3.9	4.3	<0.001
Combined data	%HRR	28.3	25.2	0.081
(coil and winch)	km h^{-1}	4.2	4.8	<0.001

P values indicate the significance of the differences eventually found between the steel cable and the synthetic rope treatments (same row)

Table 4 Test 2: comparison of relative heart rate and work pace (105 cycles)

Gradient	Work activity	Distance	Subject		Steel	Synthetic	*P*
Moderate (15%)	Pulling (uphill)	m	A	%HRR	48.0	45.0	0.5002
		46.2		Km h^{-1}	2.7	3.0	0.2506
			B	%HRR	**51.5**	**47.8**	**0.0495**
		46.1		Km h^{-1}	**3.5**	**2.9**	**0.0117**
	Hooking		A	%HRR	37.9	33.8	0.1910
			B	%HRR	**39.1**	**33.6**	**0.0200**
	Winching (downhill)		A	%HRR	21.6	21.3	0.8288
				Km h^{-1}	**1.0**	**0.9**	**0.0614**
			B	%HRR	27.1	25.2	0.2967
				Km h^{-1}	1.0	0.9	0.4182
Steep (45%)	Pulling (uphill)		A	%HRR	**53.4**	**65.1**	**0.0003**
		39.1		Km h^{-1}	2.5	2.5	0.9384
			B	%HRR	**58.5**	**62.8**	**0.0424**
		42.8		Km h^{-1}	3.1	2.9	0.4062
	Hooking		A	%HRR	**42.4**	**54.6**	**0.0010**
			B	%HRR	44.9	42.6	0.3943
	Winching (downhill)		A	%HRR	**21.9**	**29.2**	**<0.0001**
				Km h^{-1}	**1.1**	**0.9**	**0.0002**
			B	%HRR	28.7	29.8	0.4827
				Km h^{-1}	**1.1**	**0.8**	**<0.0001**

P-values indicate the significance of the differences eventually found between the steel cable and the synthetic rope treatments (same row); bold characters represent values whose differences have significance level $< 10\%$

for the transportation of a cable coil than for the transportation of a fully equipped mini-winch, where the weight reduction benefit offered by cable replacement was less dramatic. The same trends were visible for all operators, although some were more affected than others.

Table 4 reports the results of test 2, which was conducted under operational conditions. The results are split according to the two main slope gradient classes, and the comparison is presented only for the three main work activities during which operators needed to handle the cable: pulling the cable, hooking the load and following the load during winching. In fact, operators did not touch the cable during winching, and this activity was added to the analysis because it follows immediately the pulling and hooking tasks. Hence, its inclusion may help in detecting any carry-over effects from the previous two activities, given the limited time available between tasks for physiological recovery. The results are presented separately for the two test subjects, where subject B represents the control. When working on moderate slopes, the use of synthetic rope seemed to benefit only operator B, who experienced a significantly lower physiological workload during the pulling and the hooking activities. However, operator B was the control and did not carry the rope. The reduced workload could depend on the fact that he kept a slower work pace during the synthetic rope runs, than he did during the steel cable runs. On steep slopes, both operators experienced a heavier physiological workload when pulling and hooking under the synthetic rope treatment, than under the steel cable treatment. The increase was statistically significant and was not matched by any parallel increase in work pace. Hence, test 2 seemed to deny the reduced workload benefits attributed to the use of synthetic rope.

The results from test 3 were also inconclusive. The use of synthetic rope did produce a statistically significant reduction of the physiological workload experienced by operator E when pulling the rope, and such reduction was combined with a significant increase in work pace (Table 5). However, no similar workload reductions were observed for operators F and G when pulling. On the contrary, the workload for operator G was higher when pulling synthetic rope rather than steel cable, and the increase was statistically significant. No significant differences between treatments were observed for the other work activities, with the exception of work pace during winching. Here differences went opposite directions for operators E and F.

In both tests 2 and 3, winching speed tended to be slower with synthetic rope, possibly due to a more cautious use of the new medium.

Figure 1 shows the distribution of total test time by %HRR classes for each of the 5 subjects applied to tests 1 and 2, regardless of cable type. Total test time includes all work site activities except for preparation to work, and contains such tasks as rest, maintenance and waiting. Relative heart rate was also recorded at the end of any such activities, and resulted significantly lower than that recorded for productive work activities (pulling the cable, hooking the load etc.). There were remarkable individual differences in the physiological workload experienced by the different operators: subjects E and F experienced a heavy workload (%HRR >40) for 60% of the time; on the other hand, subject G never entered the heavy workload zone, and stayed within the light workload zone (%HRR <20) for over 40% of the time. As expected, the proportion of time during which the operators experienced a heavy workload increased with slope gradient. Figure 2 shows the breakdown of total test time by activity for each of the five subjects. Concerning test 3, it appears that the subject experiencing the highest workload (F) also spent a higher proportion of his work time pulling the cable, compared to the others.

Table 5 Test 3: comparison of relative heart rate and work pace (126 cycles)

Work activity	Subject	Distance		Steel	Synthetic	*P*
Pulling (downhill)	E	m	%HRR	**47.1**	**42.4**	**0.0977**
		47.9	km h^{-1}	**1.9**	**2.4**	**0.0434**
	F		%HRR	49.6	51.3	0.4626
		61.5	km h^{-1}	2.6	2.5	0.5473
	G		%HRR	**24.4**	**33.8**	**0.0015**
		37.4	km h^{-1}	2.9	3.0	0.9024
Hooking	E		%HRR	45.7	49.6	0.2008
	F		%HRR	52.0	51.9	0.9652
	G		%HRR	24.2	29.1	0.1192
Winching (uphill)	E		%HRR	41.1	42.5	0.6561
			km h^{-1}	**1.1**	**1.4**	**0.0899**
	F		%HRR	52.3	49.3	0.1967
			km h^{-1}	**1.6**	**1.1**	**<0.0001**
	G		%HRR	31.9	28.8	0.5053
			km h^{-1}	1.5	1.4	0.8346

P-values indicate the significance of the differences eventually found between the steel cable and the synthetic rope treatments (same row); bold characters represent values whose differences have significance level <10%

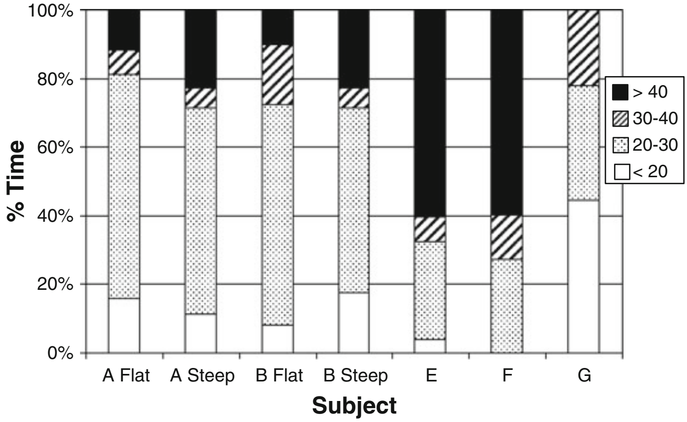

Fig. 1 Percent of test time spent at different %HRR level classes

Both the effect of slope gradient and the individual variability in the response to physiological load are confirmed by the data in Table 6. This reports the average workload experienced by each operator for the whole duration of the test, which can be assimilated to the average working day, due to the inclusion of all work activities in representative proportions. The same table also shows the total duration of the observation time, and the percent incidence of pauses (rest, maintenance and waiting time) over the total observation time. That allows estimating the time that

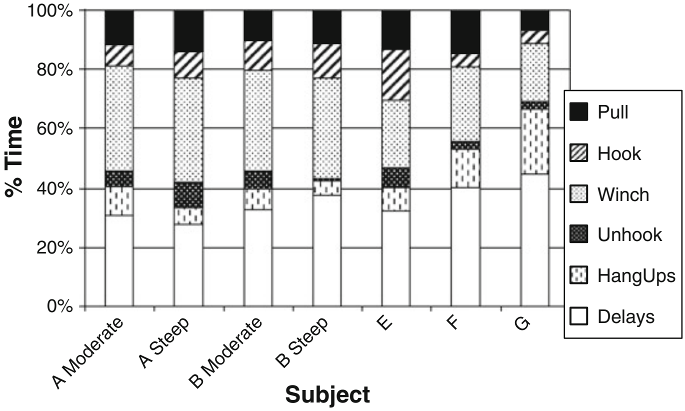

Fig. 2 Percent of test time spent for different activities

Table 6 Physiological workload indicators recorded during tests 2 and 3, duration of the individual observations per subject, percent incidence of recovery time over total test time

Subject #	Tests (h)	Avg HRw (bpm)	Avg. HRR (%)	HRw/HRr ratio	Pauses (%, time)
A (on moderate slope)	8.1	97.0	25.0	1.45	30.8
A (on steep slope)	6.0	107.7	30.4	1.54	27.8
B (on moderate slope)	8.3	89.1	29.4	1.71	32.6
B (on steep slope)	6.2	107.4	30.8	1.41	37.4
E	12.2	108.9	38.8	1.67	32.4
F	6.6	94.4	41.9	1.89	40.4
G	5.5	89.1	23.7	1.49	44.6

HRw heart rate at work, *bpm* beats per minute, *HRR* relative heart rate at work, %, *HRr* heart rate at rest

each subject devoted to active recovery in order to maintain the average %HRR indicated in the table. Subject F (oldest) worked to the limit of long-term physiological sustainability, and subject E was just a few point percent below the critical 40% threshold. On the contrary, subject G (marathoner) was very well into the comfort zone, and took more rest breaks than the others. It must also be noted that subject F pulled the rope on a longer distance compared to the others, whereas subject G pulled on the shortest distance. Overall, subjects A and B experienced rather heavy work days, resulting in a mean %HRR in the range of 30 on steep slopes.

It must also be noted that the average workloads experienced by subjects E and F were higher than those experienced by subjects A and B, although A and B pulled uphill, whereas the others pulled downhill. However, subjects E and F kept a higher production rate than subjects A and B: their crew performed 126 downhill pulls in 31 h (4 pulls per hour), whereas the crew joined by A and B only performed 105 uphill pulls in the same time (3.3 pulls per hour). Both crews consisted of three

Table 7 Relative heart rate at work for the two subjects in test 2: effect of slope gradient and cable type

Subject	Moderate slope	Steep slope	*P*
A	28.7	36.5	<0.0001
B	34.1	37.6	0.0028
Both	31.4	37	<0.0001
Subject	Steel	Synthetic	*P*
A	30.6	33.8	0.0219
B	36.9	34.4	0.0323
Both	33.8	34.1	0.7179

P-values indicate the significance of the differences eventually found between treatments (same row)

operators, although the third operator in crew two was not included in the physiological workload study because he did not perform any pulling or walking activity.

Table 7 presents data from test 2 and shows the clear effect of slope gradient, near to the ambiguous effect of cable type.

Discussion

The study under controlled conditions demonstrated that the replacement of steel cable with synthetic rope does offer a statistically significant reduction of physiological workload. This reduction is related to the overall load weight reduction allowed by the replacement of steel cable. Hence, the effect is weaker for the mini-winch, which has a substantial empty weight (52 kg) and remains relatively heavy despite the replacement of steel cable. These result agree with those obtained from similar tests performed in North America by Garland et al. (2002).

However, the two tests conducted under real work conditions failed to produce conclusive evidence for the reduced workload offered by synthetic rope.

Many different factors determine the physiological workload experienced by choker setters, and it is likely that some of these factors have a stronger effect than the weight of the cable itself. One of these factors is slope gradient, which is known to have a strong and negative impact on the physiological workload of forestry tasks (Kirk and Parker 1996; Sullman and Byers 2000). Walking up and down a steep slope may generate such a heavy workload to cover all other effects. Another possible explanation is that the extreme variability offered by real forest environments generated excessive background noise and confounded the results. This could be the case of test 2, where both the test and the control subject experienced statistically significant increases of the physiological workload under the steep slope synthetic rope treatment, even if only one of the subject actually pulled the rope. On the other hand, it is almost impossible to contain all sources of variability under actual operational conditions, and it is very difficult to develop

objective numerical indicators that may transform such micro-variability into a meaningful covariate (Garland 1990). This conclusion seems to be confirmed in Table 7.

Furthermore, pulling a winch cable is not exactly the same as carrying a dead weight, because the operator must generate enough force to turn the winch drum, winning its weight and any eventual friction. While the overall weight to be turned was significantly reduced by the installation of synthetic rope, the friction generated by the specific settings of the drum transmission was the same for both treatments. This force can been relatively high, and it may partially offset any benefits obtained from the use of synthetic rope (Pilkerton et al. 2004b). When installing synthetic rope on a winch, winch settings should be adjusted to the much lower inertial force generated by the reduced drum weight, in order to gain the full benefit of synthetic rope adoption.

Finally, it is possible that the workload recorded for one of the treatments contained some carry-over effect from the other treatment, since the two treatments were alternated all along the working day. That highlights the difficulty encountered when designing such a trial, where close alternation of the two treatments implies the risk of carry-over effects. On the other hand, separating the treatments more sharply within the working day or between working days may introduce the error caused by circadian or daily variability.

Regardless of cable type, the daily average for the heart rate of the choker setters observed in this study ranged from 90 to 110 beats per minute, exactly matching the figures obtained for New Zealand choker setters by Kirk and Sullman (2001). That places choker setting within the limits of a “moderate workload” activity (Åstrand and Rodahl 1988). On the other hand, assuming relative heart rate at work as an indicator of physiological workload will move subjects E and F up one level, and into the “rather heavy workload” class (Chamoux et al. 1985). That is in agreement with the data presented by Frimati et al. (1979), and especially by Cristofolini et al. (1990) in a study conducted exactly in the same region, under typically Alpine conditions.

Comparison with the workloads experienced by subject working in other sectors is made easier by using the ratio between heart rate at work and heart rate at rest (Diament et al. 1968). The values obtained from our study range from 1.41 to 1.89, and match very closely the 1.84 figure obtained by Kirk and Sullman (2001). These figures are substantially higher than those recorded for tree pruning (1.45, Kirk and Parker 1996), nursing (1.45, Fordham et al. 1978), car assembly work (1.45, Minard et al. 1971) and steel factory work (1.28, Vitalis et al. 1994).

Individual variability is very high. Subject G experienced the lowest physiological workload, but he was a trained marathon athlete and took frequent rest pauses. On the contrary, the highest workload was experienced by subject F, who was relatively old and had the smallest physiological reserve to tap into.

Moreover, the results obtained in this study are only valid for a relatively small cable size (10 mm diameter): the absolute weight reduction offered by steel replacement is proportional to cable size, and would have been much larger if the test was conducted on a more powerful winch, equipped with 12, 14 or even 16 mm

cables. In this case, testing under real work conditions might provide clearer results, as the subjective evidence offered by Ewing (2003) seems to imply.

The study failed to provide conclusive evidence for the workload reduction achieved under operational conditions with the introduction of synthetic rope, but the subjective reactions of all test volunteers were very positive. All stated they preferred synthetic rope to steel cable, as also reported by Garland et al. (2002). In fact, synthetic rope offers other benefits than just weight reduction: it is supple, it does not bind on the winch drum, and especially it does not puncture the hands of the workers handling it.

Furthermore, the weight reduction offered by synthetic rope produces important benefits whenever the mass of the equipment must be kept as low as possible. That is the case of mini-winches (Ewing 2001), ATVs (Dunnigan 1993) and motorized yarder carriages (Garland et al. 2004; Spinelli et al. 2010).

Conclusions

The replacement of steel with synthetic fiber allows a dramatic reduction of cable weight, and a significant reduction of the physiological workload experienced by the operators carrying the cable. However, when it comes to direct winching under actual operational conditions, the simple replacement of steel cable with synthetic rope does not guarantee these same benefits: other factors come into play, and especially terrain profile, individual variability and the conditions of the base equipment. This highlights the importance of multi-component intervention in ergonomic improvements (Silverstein and Clark 2004): the replacement of cable should be accompanied by equipment adaptation and organizational changes (Denis et al. 2008), with the additional purpose of increasing work safety as well (Wirth and Sigurdsson 2008). Of course, the results of this study are only valid for direct winching with small to medium size cables. Under different conditions, it is possible that the simple replacement of steel cable with synthetic rope may allow a significant reduction of operator workload.

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